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(54) **SUBSTRATE-LIKE PARTICLE SENSOR**

(76) Inventors: **Dennis J. Bonciolini**, Tigard, OR (US); **Craig C. Ramsey**, West Linn, OR (US); **DelRae H. Gardner**, Tualatin, OR (US); **Felix J. Schuda**, Saratoga, CA (US)

Correspondence Address:
Christopher R. Christenson
WESTMAN, CHAMPLIN & KELLY, P.A.
Suite 1400, 900 Second Avenue South
Minneapolis, MN 55402-3319 (US)

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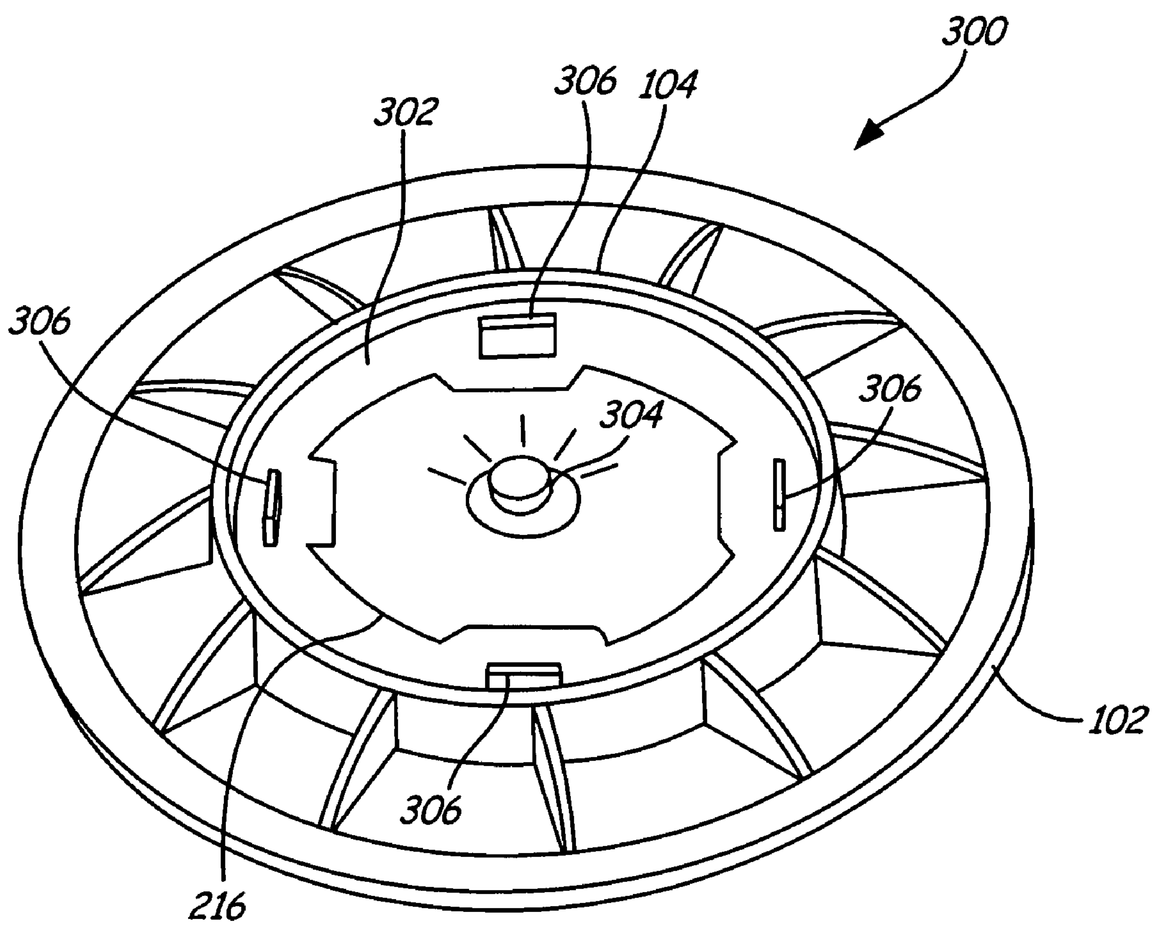
(52) **U.S. Cl.** **356/338**

(57) **ABSTRACT**

A substrate-like particle sensor includes a substrate-like base portion and an electronics enclosure disposed on the substrate-like base portion. A power source is located within the electronics enclosure. A controller is operably coupled to the power source. A particle sensor is operably coupled to the controller and provides an indication to the controller of at least one particle present near the particle sensor.



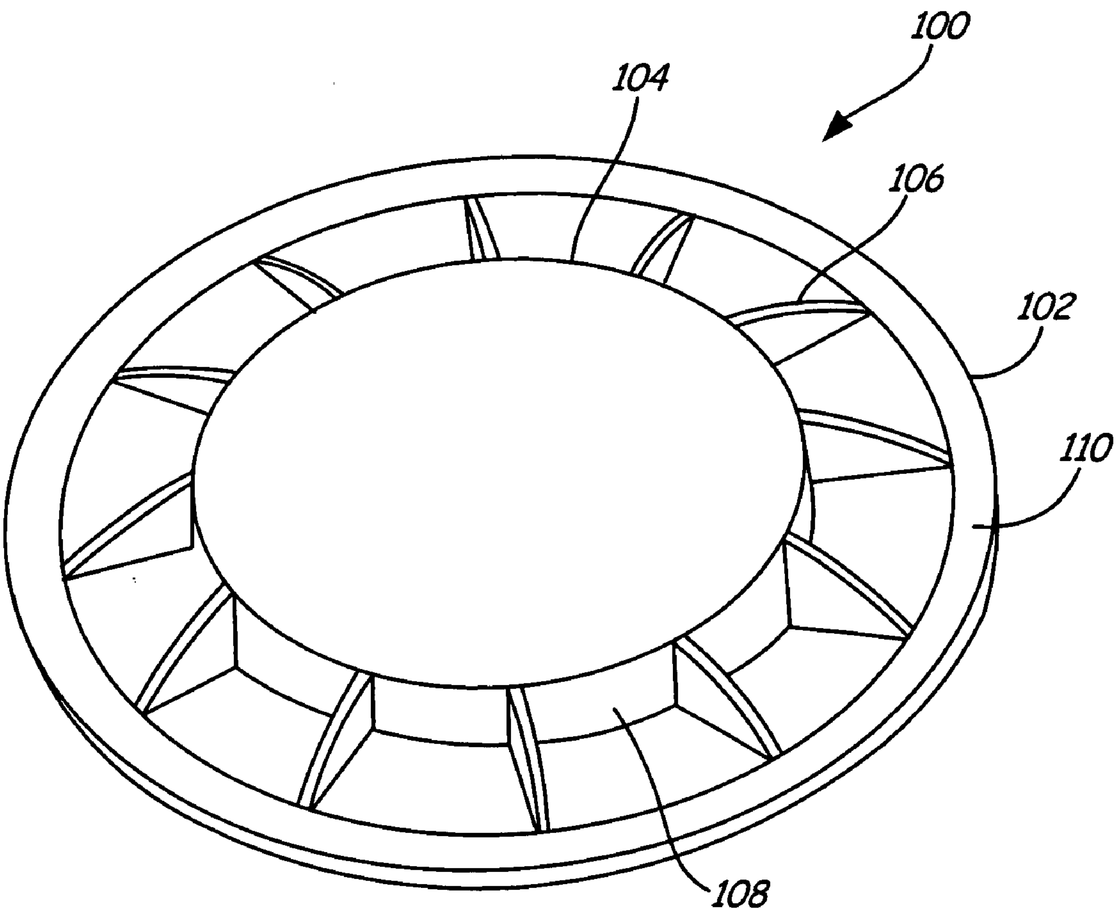
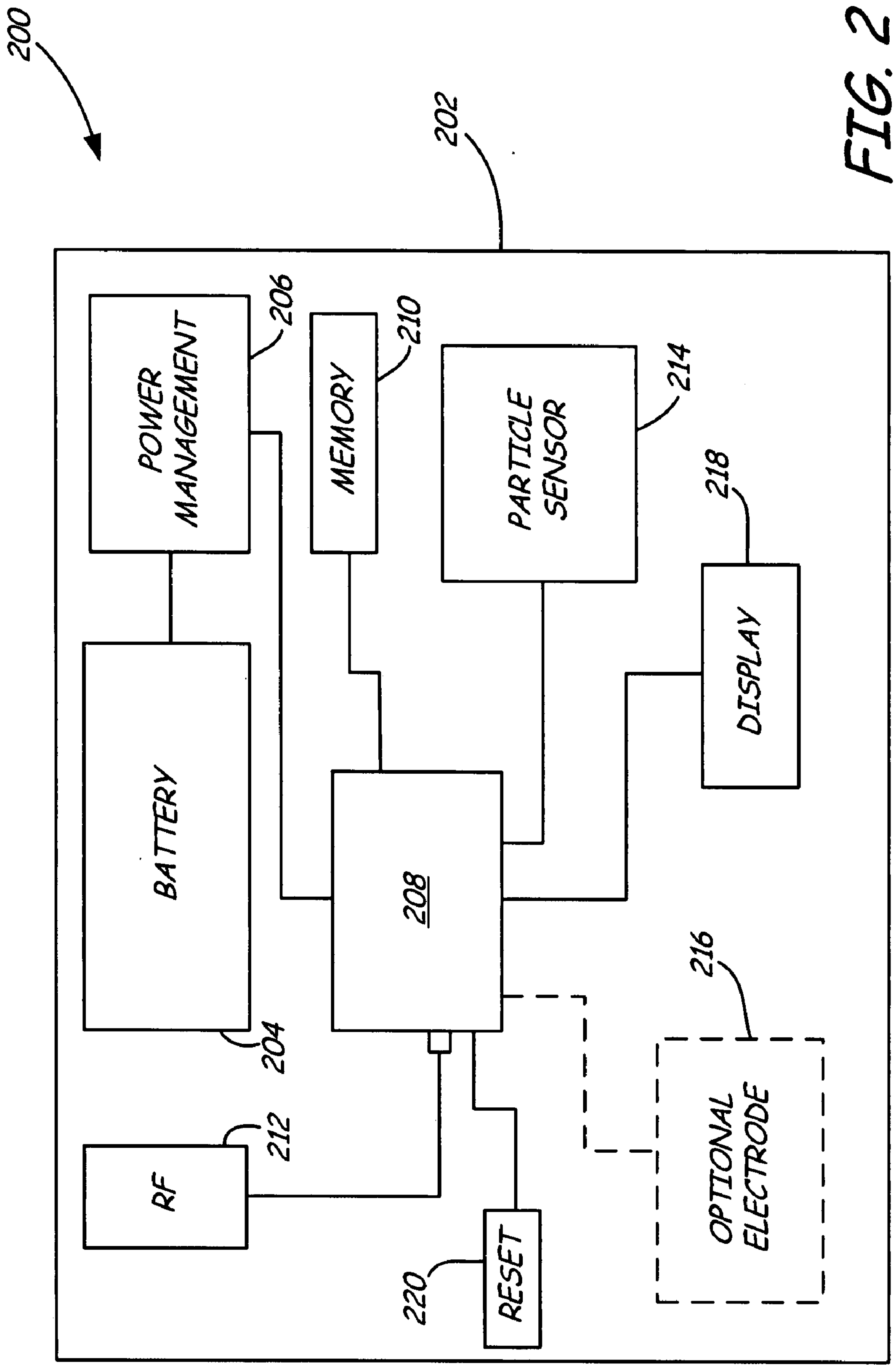


FIG. 1



200
202
POWER MANAGEMENT
206
MEMORY
210
PARTICLE SENSOR
214
218
DISPLAY
BATTERY
204
208
216
OPTIONAL ELECTRODE
RF
212
RESET
220

FIG. 2

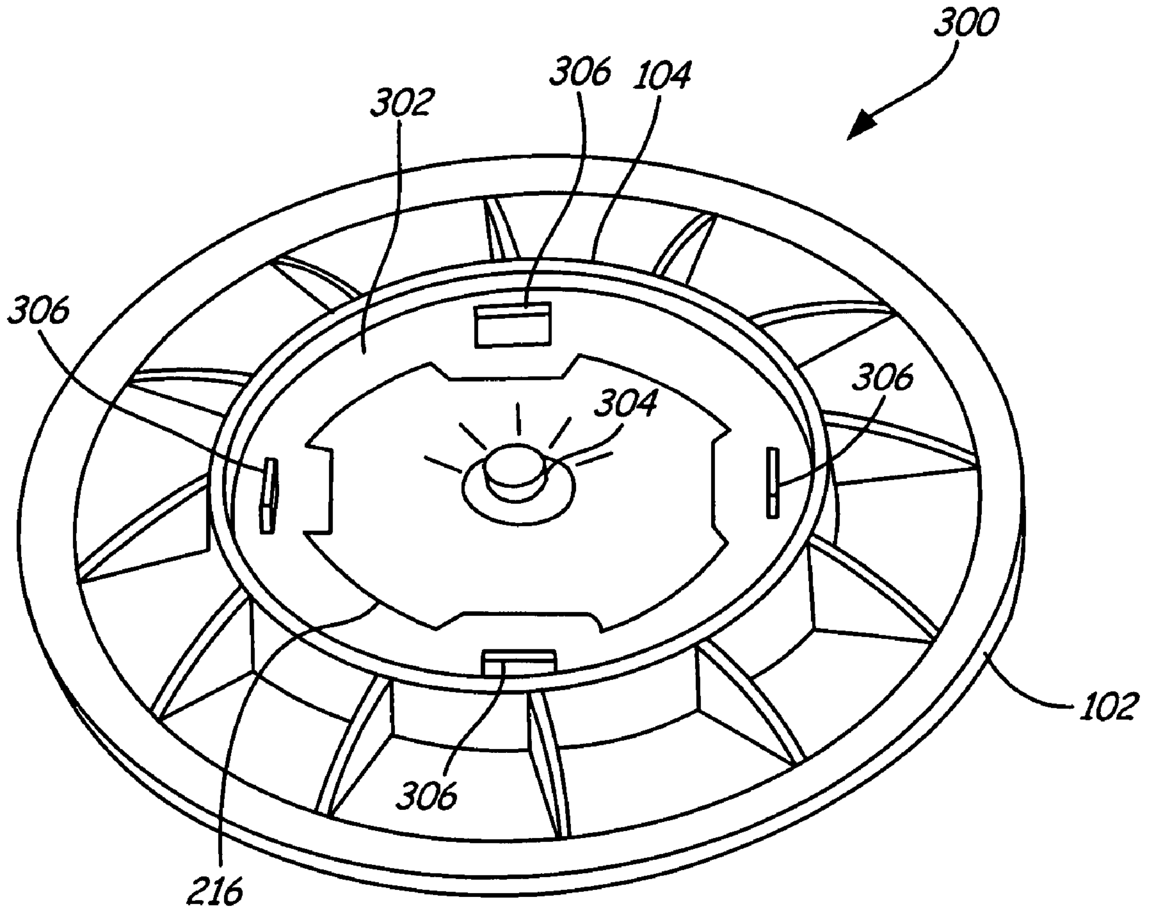


FIG. 3

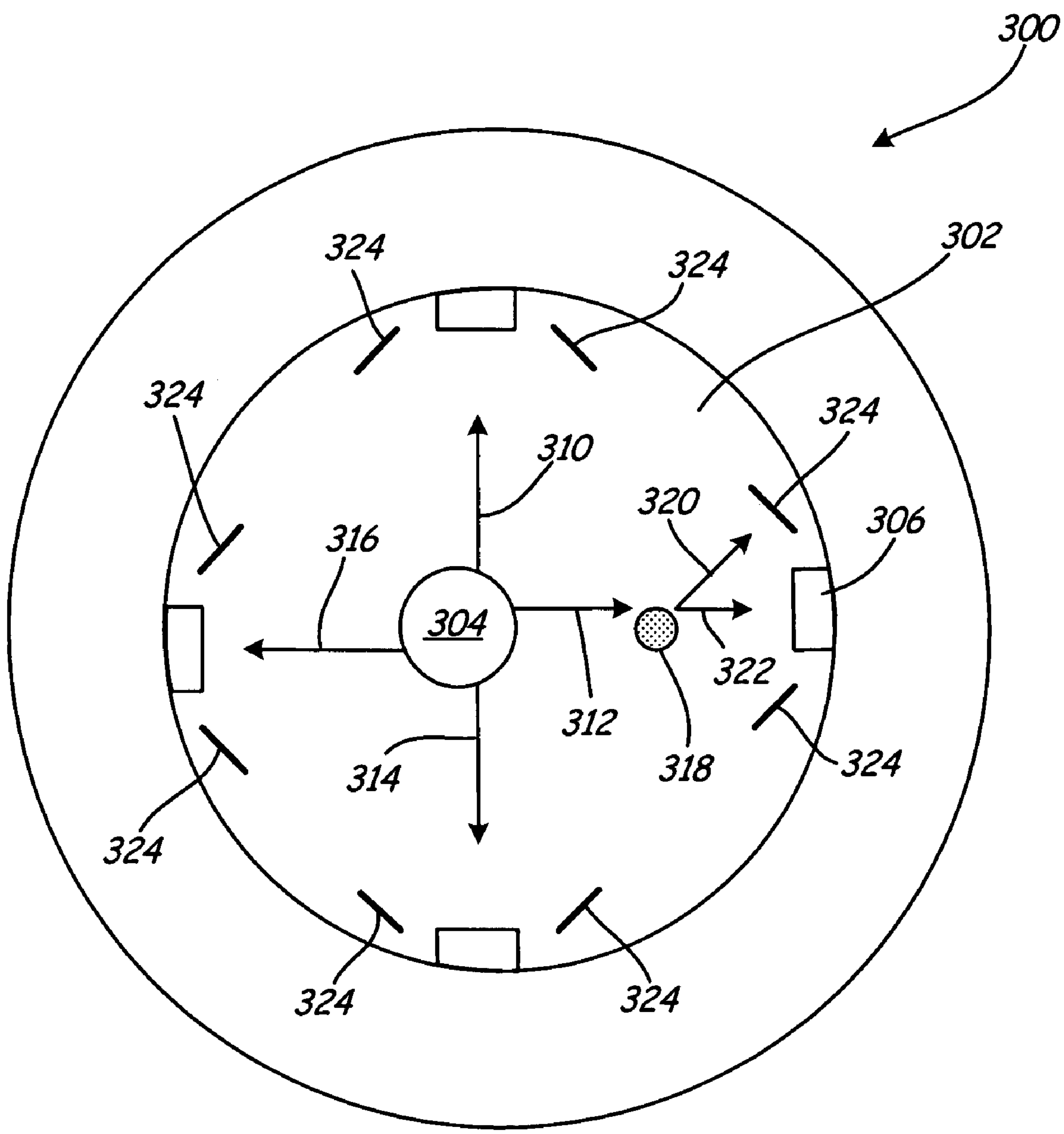

300
302
324
324
324
324
310
320
306
316
304
322
312
324
314
318
324
324
324

FIG. 4

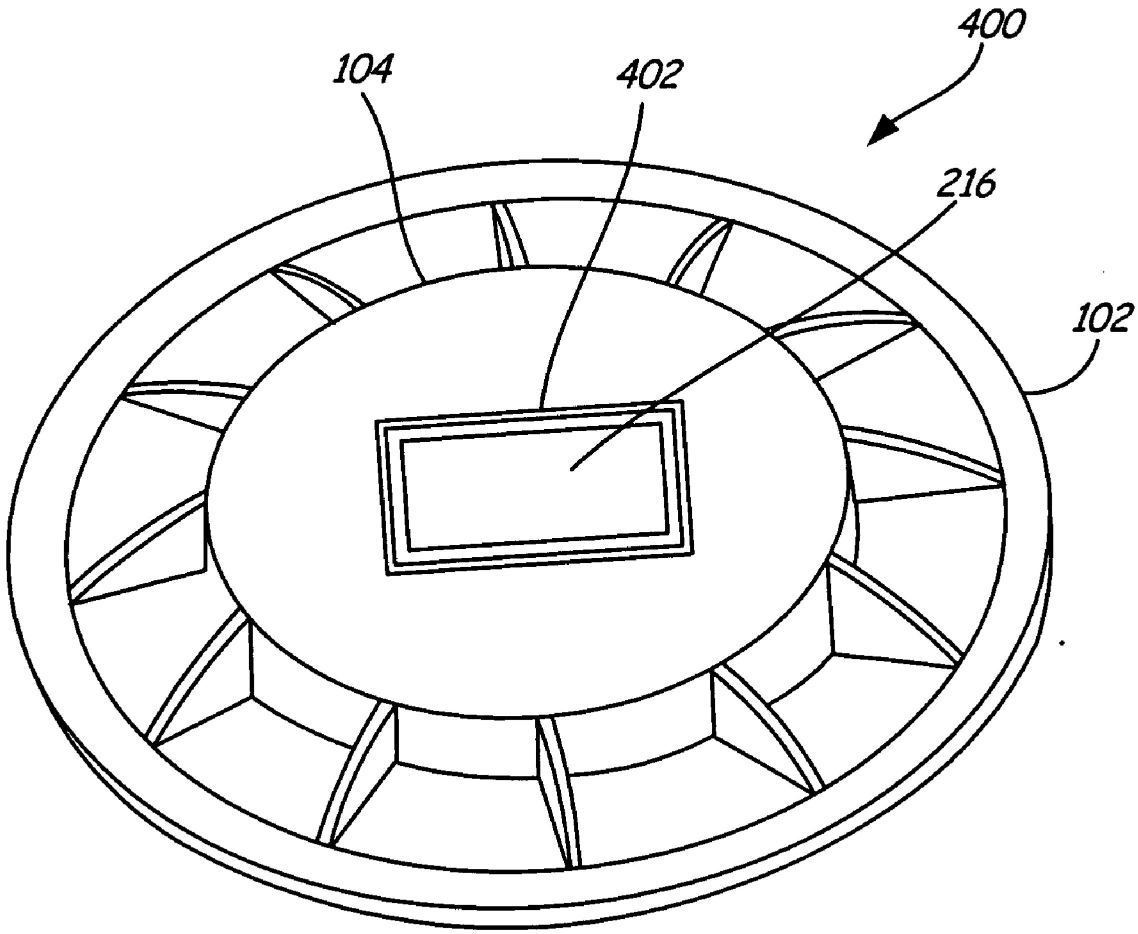


FIG. 5

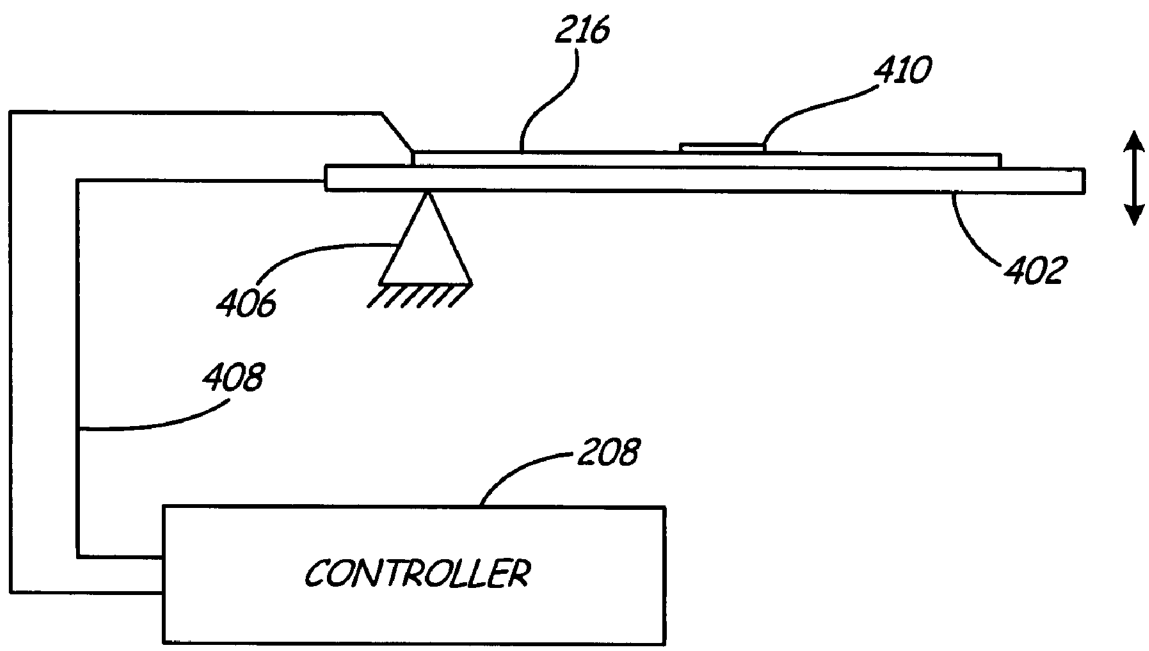


FIG. 6

SUBSTRATE-LIKE PARTICLE SENSOR

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application is based on and claims the benefit of U.S. provisional patent application Ser. No. 60/848,336, filed Sep. 29, 2006, the content of which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] The leading edge of the semiconductor processing industry is currently advancing production to the 65 nanometer and 45 nanometer nodes. Further, development is currently underway at the 32 nanometer and 22 nanometer nodes. Accordingly, it is increasingly critical that semiconductor processing tools and the processing itself be controlled to tolerances and conditions never previously required. The cost of wafer scrap and maintenance downtime continues to drive the desire to control processes and equipment to tighter levels, and as other problems arise that were insignificant to processes above 100 nanometers, process and equipment engineers look for new and innovative ways to better control semiconductor processing.

[0003] During the manufacture of semiconductor wafers, there are multiple tools and process steps to which a wafer is exposed. During each of these steps there are potential defects that may be caused by dirty equipment and/or poor process conditions that can cause degradation in yield of the final integrated circuit devices due to microscopic particles being deposited on the wafer's surface. Thus, it is critical to keep all process stages and steps as clean as reasonably possible and to be able to monitor the condition of these various stages before committing wafers to the process. This is important because each wafer may contain the circuitry for tens or even hundreds of integrated circuit devices, and a single lost wafer may result in hundreds or thousands of dollars worth of scrap.

[0004] Traditionally, wafers are test-run through the semiconductor processing tool and particles on the wafer are counted both before and after the test run. The difference in the number of particles is then attributed to the tool. This is a time-consuming process and may not provide any indication of where, within the tool, the particles were deposited. Accordingly, if too many particles are found on a given test run wafer, it simply indicates that the semiconductor processing tool is too dirty and that further technician efforts are required to open the tool, identify the source(s) of particles, and generate appropriate corrective action. Once this process is complete, the wafer must be test run again and the entire process repeated until there is simply an indication that the semiconductor processing tool is suitably clean.

SUMMARY

[0005] A substrate-like particle sensor includes a substrate-like base portion and an electronics enclosure disposed on the substrate-like base portion. A power source is located within the electronics enclosure. A controller is operably coupled to the power source. A particle sensor is operably coupled to the controller and provides an indication to the controller of at least one particle present near the particle sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. **1** is a perspective view of a wireless substrate-like sensor with which embodiments of the present invention are particularly useful.

[0007] FIG. **2** is a block diagram of a wireless substrate-like particle sensor in accordance with an embodiment of the present invention.

[0008] FIG. **3** is a perspective view of a wireless substrate-like particle sensor **300** in accordance with an embodiment of the present invention.

[0009] FIG. **4** is a top plan view illustrating a sensor in accordance with an embodiment of the present invention.

[0010] FIG. **5** is a perspective view of a wireless substrate-like particle sensor in accordance with another embodiment of the present invention.

[0011] FIG. **6** is a diagrammatic view of the MEMS mass-based embodiment described with respect to FIG. **5**.

DETAILED DESCRIPTION

[0012] Embodiments of the present invention generally provide real-time sensing of particles present within the sealed environment of a semiconductor processing tool. The sensing of particles can be done in accordance with various techniques. One exemplary technique provided herein includes optically sensing particles proximate a substrate-like wireless sensor. Another embodiment includes sensing the mass of particles deposited upon a mechanical structure coupled to the wireless substrate-like sensor.

[0013] FIG. **1** is a perspective view of a wireless substrate-like sensor with which embodiments of the present invention are particularly useful. Sensor **100** includes substrate-like portion **102** that is preferably sized to have a diameter that is equal to that of a standard substrate size. Exemplary sizes include a 200 millimeter diameter, or a 300 millimeter diameter. However, as different standards are developed or employed, this dimension can vary. Sensor **100** includes electronics housing or enclosure **104** that is disposed upon substrate-like portion **102**. In order to increase rigidity of the overall sensor **100**, a plurality of fins or struts **106** are provided that couple side wall **108** of electronics enclosure **104** to surface **110** of substrate-like portion **102**. In order to pass easily through the sealed semiconductor processing chamber, it is desirable for substrate-like sensor **102** to have a form factor that is very similar, if not identical, to an actual substrate. Common wafer dimensions and characteristics may found in the following specification: SEMI M1-0302, "Specification for Polished Monochrystoline Silicon Wafers", Semiconductor Equipment and Materials International, www.semi.org.

[0014] FIG. **2** is a block diagram of a wireless substrate-like particle sensor in accordance with an embodiment of the present invention. Sensor **200** includes electronics enclosure **202**, which may be identical to enclosure **104**. Disposed within enclosure **202** are power source **204**, power management module **206**, and controller **208**. Additionally, memory **210** is also disposed within enclosure **202** and is coupled to controller **208**. Further still, radio frequency module **212** is disposed within enclosure **202** and coupled to controller **208**.

[0015] While particle sensor **214** is illustrated in FIG. **2** as being disposed within enclosure **202**, it may form part of enclosure **202**, or may be disposed proximate, but external to enclosure **202**.

[0016] As illustrated in FIG. **2**, power source **204** is preferably a battery disposed within enclosure **202** and is coupled to controller **208** via power management module **206**. Preferably, power management module **206** is a power management integrated circuit available from Linear Technology Corporation under the trade designation LTC3443. Controller **208** is preferably a microprocessor available from Texas Instruments under the trade designation MSC1211Y5. Controller **208** is coupled to memory module **210**, which can take the form of any type of memory, including memory that is internal to controller **208** as well as memory that is external to controller **208**. The preferred controller includes internal SRAM, flash RAM and boot ROM. Memory module **210** also preferably includes external flash memory having a size of 64K×8. Flash memory is useful for storing such non-volatile data as programs, calibration data, and/or non-changing data as may be required. The internal random access memory is useful for storing volatile data relevant to program operation.

[0017] Controller **208** is coupled via a suitable port, such as a serial port, to radio frequency communication module **212** in order to communicate with external devices. In one embodiment, radio-frequency module **212** operates in accordance with the well-known Bluetooth standard, Bluetooth core specification version 1.1 (Feb. 22, 2001), available from the Bluetooth SIG (www.bluethooth.com). One example of module **212** is available form Mitsumi under the trade designation WMLC40. Additionally, other forms of wireless communication can be used in addition to, or instead of, module **212**. Suitable examples of such wireless communication include any other form of radio frequency communication, acoustic communication, infrared communication or even communication employing magnetic induction.

[0018] Controller **208** is coupled to particle sensor **214** which is configured to sense one or more particles proximate sensor **200** within the sealed environment of a semiconductor processing tool. Sensor **214** can preferably sense not only particle presence (in order to generate particle counts), but can also sense a characteristic of individual particles, such as mass and/or size. While an embodiment described below specifically addresses particle mass, particle size can be sensed by using a multi-pixel image sensor, such as a line sensor, or array, and detecting how many pixels sense the shadow of a particle.

[0019] Sensor **200** can also include optional electrode **216** which preferably forms an electrostatic plate that is disposed to attract particles floating in the air proximate sensor **200** to particle sensor **214** to be sensed more efficiently. The details of the way in which optional electrode **216** performs this function will be described with respect to distinct embodiments described below.

[0020] Sensor **200** preferably includes a display **218** that is configured to provide a particle count and/or display a go/no go indication to the process engineer. Additionally, in order to reset the particle count, reset button **220** is also provided and is coupled to controller **208**.

[0021] FIG. **3** is a perspective view of a wireless substrate-like particle sensor **300** in accordance with an embodiment of the present invention. Sensor **300** bears many similarities to sensors **100** and **200**, and like components are numbered similarly. Sensor **300** has an electronics enclosure **104** with a recessed surface **302**. Within electronics enclosure **104** below surface **302**, all of the electronics, such as those illustrated in FIG. **2**, are disposed. The embodiment illustrated in FIG. **3** provides an optical technique for measuring particles proximate sensor **300**. Specifically, particle sensor **214** includes light source **304** disposed near the center of surface **302**. Light source **304** may be an LED, a laser, or any other suitable light source. At least one illumination sensor **306** is disposed near a periphery of surface **302**. Further, it is preferred that a number of mirrors (shown in FIG. **4**) be included near the periphery of surface **302**. Illumination emanating from source **304** essentially travels out in all directions, and, when no particles are present, generates substantially constant illumination signals at each of sensors **306**. When one or more particles enters the area between source **304** and one of detectors **306**, that detector **306** will note a fluctuation in the light intensity. This fluctuation can increment the particle count, or be stored in some other suitable fashion. While FIG. **3** illustrates source **304** as generating illumination in substantially all directions, it is expressly contemplated that source **304** may generate one or more directional beams, whether comprised of structured illumination or not, that may interact with one or more mirrors before finally impinging upon a detector **306**. In this way, more of the area proximate surface **302** can be monitored for interactions with particles.

[0022] FIG. **3** also illustrates optional electrode **216** in the form of a relatively large plate. Electrode **216** is preferably an electrostatic electrode that is maintained, in known fashion, at a potential that will attract particles.

[0023] While the embodiment illustrated with respect to FIG. **3** illustrates one or more beams or rays of illumination moving from a static source to a plurality of static sensors, it is also expressly contemplated that one or more beams could be scanned, or otherwise passed proximate surface **302**, for example by using moving mirrors. Further still, in either the embodiment shown in FIG. **3**, or the scanning beam embodiment, the beam or illumination may be collimated vertically, but diverging horizontally so that the angular coverage is enhanced without their physical scanning.

[0024] FIG. **4** is a top plan view illustrating sensor **300** in accordance with an embodiment of the present invention. Source **304** generates illumination in directions **310**, **312**, **314** and **316**. Illumination **312** is illustrated impinging a particle **318**, which is shown with a grossly exaggerated size. A portion of the illumination is then deflected as illustrated at line **320**, and only illumination **322** reaches detector **306**. Detector **306** senses this momentary change in illumination intensity, and registers a particle to controller **208**. FIG. **4** also illustrates a number of mirrors **324** that help facilitate or otherwise generate larger optical paths along the plane proximate and substantially parallel to surface **302**.

[0025] While the illumination described with respect to the embodiments illustrated in FIGS. **3** and **4** can take any suitable form, it is preferred that the illumination have a relatively short wavelength, such as in the blue, or even ultraviolet spectral range, since longer wavelength illumination will be less scattered by the very small particles. Accordingly, short wavelength illumination is preferable since process technology is advancing to smaller and smaller critical dimensions. Further, while the optical-based embodiment described with respect to FIGS. **3** and **4** generally measure light emanating from a central source, one or more sensors can be used or arranged such that they do not normally see light from the centralized source, but instead see light from scattered particle interactions. Accordingly, in such embodiments, when there is no particle in the beam, there is not scattered light detected. Conversely, when there is a particle in the beam, scattered light is detected. Moreover, combinations of detectors detecting both non-scattered and scattered light can be used to reduce the likelihood of false particle detentions.

[0026] FIG. **5** is a perspective view of a wireless substrate-like particle sensor in accordance with another embodiment of the present invention. Sensor **400** bears some similarities to sensors **100** and **300**, and like components are numbered similarly. Sensor **400** differs from previously-described sensors in that sensor **400** determines particle quantity by essentially measuring the mass of particles that adhere to structure **402**. Structure **402** is preferably a microelectromechanical system (MEMS) that includes a piezoelectric element that is able to excite, or otherwise drive, structure **402** in order to determine its resonant frequency. As particles adhere to structure **402**, the mass of the combined particles/structure **402** will change, and accordingly change the resonant frequency. In order to enhance the efficiency of sensor **400**, it is also preferred that sensor **400** include optional electrostatic electrode **216** disposed on structure **402**. In this manner, particles floating proximate structure **402** will be urged, via electrostatic force, to adhere to structure **402**. Structure **402** then uses the electrostatic charge from optional electrode **216** to attract particles onto its beam or onto a proof of mass of structure **402**. While it is preferred that electrode **216** maintain either a positive or negative charge, it may also alternate to attract particles and potentially scavenge particles from the semiconductor processing tool.

[0027] FIG. **6** is a diagrammatic view of the MEMS mass-based embodiment described with respect to FIG. **5**. Specifically, structure **402** is a cantilever structure in that it is supported, as illustrated diagrammatically at support **406**, on or proximate one end. A portion of structure **402** is piezoelectric, or otherwise formed of a suitable microelectromechanical structure such that a current from controller **208** through line **408** generates movement within structure **402**. Analyzing the electrical response of the piezoelectric element, controller **208** is able to calculate, or otherwise observe changes in, the mass of structure **402**, and/or the resonant frequency of structure **402**. This is because, as particles are deposited on structure **402**, as indicated at reference numeral **410**, the total mass and rotational inertia of the system about support **206** changes. This change is then detected as the different resonant frequency. FIG. **6** also illustrates optional electrode **216** disposed on top of structure **402** and attracting particles **410**.

[0028] Embodiments of the present invention generally provide particle detection with a semiconductor processing tool that is in substantially real-time. This real-time feedback can be provided visually to a process engineer by virtue of the engineer viewing display **218** through a window in the process tool. Additionally, or alternatively, the real-time feedback can be provided via a radio frequency signal provided via radio frequency communication module **212**.

[0029] Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention.

What is claimed is:

1. A substrate-like particle sensor comprising:
a substrate-like base portion;
an electronics enclosure disposed on the substrate-like base portion;
a power source disposed within the electronics enclosure;
a controller operably coupled to the battery; and
a particle sensor operably coupled to the controller.

2. The substrate-like sensor of claim **1**, wherein the particle sensor employs a light source that generates a beam that is scattered by the particles, and detects the degree to which the beam is scattered.

3. The substrate-like sensor of claim **2**, wherein the light source is a laser light source.

4. The substrate-like sensor of claim **3**, and further comprising at least one mirror disposed to bend the beam across a surface of the substrate-like sensor.

5. The substrate-like sensor of claim **2**, wherein the light source is an LED light source.

6. The substrate-like sensor of claim **5**, and further comprising at least one mirror disposed to bend the beam across a surface of the substrate-like sensor.

7. The substrate-like sensor of claim **1**, wherein the particle sensor employs a device that measures mass of accumulated particles.

8. The substrate-like sensor of claim **7**, wherein the device is a MEMS device.

9. The substrate-like sensor of claim **1**, and further comprising a wireless communication module that is coupled to the controller and is configured to communicate particle sensing information while the substrate-like sensor is positioned within the wafer processing system.

10. The substrate-like sensor of claim **1**, wherein the controller is configured to calculate a quantity of particles present within the wafer processing system based upon a parameter sensed by the sensor.

11. The substrate-like sensor of claim **10**, and further comprising a display operably coupled to the controller and configured to provide an indication of particle quantity.

12. The substrate-like sensor of claim **1**, and further comprising a display operably coupled to the controller and configured to provide an indication of relative to particle quantity.

13. The substrate-like sensor of claim **1**, and further comprising a reset button operably coupled to the controller.

14. The substrate-like sensor of claim **12**, wherein the display indicates go/no go based upon a level of detected particles within the wafer processing system.

15. The substrate-like sensor of claim **1**, wherein the sensor is configured to provide an indication of particle size.

* * * * *